Addressing the impact of land crabs on rodent eradications on islands

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Consumption of rodent bait by land crabs, leaving some rodents unexposed, has been described as one potential reason why several rodent eradications undertaken on mesic-tropical islands have failed. Strategies to overcome the issue have been proposed but all increase the risk, cost or logistics of running an eradication operation. To quantify the impact of land crabs and assess the feasibility of achieving rodent eradication using a standard bait application rate used in temperate climates, we measured crab density, rates of bait take and exposure of rats to bait on Vahanga Atoll in French Polynesia. The two methods used to measure crab density were closely correlated and agreed with anecdotal observations, suggesting they were a reliable index of crab numbers. Rates of bait take were closely correlated with crab density providing a potential means of predicting bait take in a crab dominated ecosystem such as Vahanga, an advantage when planning a rodent eradication attempt. At some sites on Vahanga, crabs were in sufficient numbers (up to 5 900/ha) to rapidly reduce bait availability but even at these sites rats were able to access bait. The result suggests that achieving rat eradication on some mesic-tropical islands may be possible using a typical temperate climate bait application rate. However, our results should be applied with caution because we did not determine the amount of bait consumed by rats.

Key words: mesic-tropical, French Polynesia, rat, restoration, conservation, biodiversity

INTRODUCTION

ERADICATION of invasive rodent species from islands is now an established technique for protecting threatened species and ecosystems (Donlan *et al.* 2003; Towns and Broome 2003). However, few rodent eradications have been attempted on mesic-tropical islands (Howald *et al.* 2007) and the need for further refinement of techniques in this type of environment has been identified (Rodriguez *et al.* 2006). Eradication programmes targeting invasive rodent species on mesic-tropical islands face an additional suite of challenges to those undertaken in temperate and polar environments. One of these is the presence of land crabs, a non-target consumer of rodent bait.

Many land crab species are omnivorous, populations can reach astonishing densities (up to 60 000 per ha) (Burggren and McMahon 1988) and species within the families Coenobitidae and Gecarcinidae have been observed eating rodent bait (Buckelew *et al.* 2005 *in litt.*; Rodriguez *et al.* 2006). Land crabs are not susceptible to poisoning by the second generation anticoagulants now commonly used for rodent eradication (Pain *et al.* 2000) and it has been suggested that, as a non-target consumer of bait, they could remove sufficient bait to create gaps in coverage leaving some rodents unexposed (Rodriguez *et al.* 2006). Land crabs were considered to be one possible reason for the failure of rodent eradication attempts undertaken on Vahanga (Blanvillain 2001 *in litt.*), Palmyra (Rauzon 2007) and Fanna and Dekehtik islands (US Fish and Wildlife Service 2011).

A number of strategies for overcoming bait interference by land crabs have been put forward (Wegmann 2008 *in litt.*), but all add to the cost or logistical complexities of a rodent eradication operation. Presenting bait in bait stations can be used effectively to reduce land crab interference (Wegmann *et al.* 2008 *in litt.*), but is more labour intensive than hand or helicopter spreading of bait and can add significantly to the cost of an operation (Howald *et al.* 2007). Bait station design and placement can also influence bait take by rodents (Clapperton 2006; Spurr *et al.* 2007), potentially increasing the risk of operational failure and their use for eradication purposes is limited to islands with negotiable terrain.

Super-saturating a land crab population with rodent bait so that some bait remains available to rodents is the only viable strategy proposed that has potential for larger islands or islands with difficult terrain. However, like other strategies, increasing the amount of bait applied not only increases the cost of an operation, but for remote islands, may add significantly to its logistics. Applying bait at higher application rates can also exacerbate the risk to non-target species. This strategy was applied on Palmyra Atoll in 2011 to target ship rats *Rattus rattus* (Wegmann 2011 *in litt.*). Extensive toxic and non-toxic bait trials to assess bait take by crabs on Palmyra resulted in a decision to apply bait at 80 and 75 kg/ha in two separate applications

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(Wegmann 2011 *in litt.*). In comparison, 8 kg/ha followed by 4.5 kg/ha is routinely used in temperate climates to achieve rat eradication successfully (Broome *et al*. 2010 *in litt.*).

To aid the planning of rodent eradications on mesic-tropical islands and to quantify the potential impact of land crabs on a rodent eradication operation utilizing a second generation anticoagulant we completed a non-toxic bait trial on Vahanga Atoll, French Polynesia. We applied bait at three different application rates (greater, similar to and less than that used in temperate climates) at discrete sites and evaluated the relationship between crab density and levels of bait interference at these sites. Using a bio-marker, we assessed the exposure of rats to bait at the different application rates and hence the feasibility of eradicating rodents at bait application rates similar to those used in temperate climates.

Methods and Analysis

Vahanga (21°17'S, 136°29'E) is located in the Acteon Group of the Tuamotu Archipelago, French Polynesia. An attempt to eradicate rats on Vahanga was completed in 2000 but was unsuccessful (Blanvillain 2001 *in litt.*) and another attempt has been proposed (Pierce *et al.* 2006 *in litt.*). Vahanga is just 7 km from Tenararo, which is one of only two mammalian pest-free islands in the Tuamotu Archipelago. Tenararo and Vahanga have been identified as a Key Biodiversity Area in Conservation International's Critical Ecosystem Partnership Fund Ecosystem Profile for the Polynesia/Micronesia Hotspot (#127) and the islands are a proposed Important Bird Area (Pierce *et al.* 2006 *in litt.*). As well as providing safe habitat on Vahanga for a number of threatened species found in the region, rodent eradication would provide increased security for Tenararo biota.

Vahanga is a typical coral atoll *c*.10 km in circumference with an outer coral reef platform and beach. The total land area of the atoll is 382 ha and the lagoon covers approximately 876 ha. Abandoned coconut *Cocos nucifera* plantation now dominates much of the island although a few small remnants of relatively unmodified vegetation, largely pandanus *Pandanus tectorius* and mikimiki *Pemphis acidula* remain.

The trial was undertaken during July and August 2007 over a period of 25 days by a team of eight people. Six study sites, between 5 ha and 6 ha in size, were established on Vahanga (Fig. 1). Sites 1-3 were on small "motu" or islets, separated from neighbouring parts of the island by "hoa", low lying areas permanently inundated by water or periodically during storm events. Site 4 was isolated to the east but part of its western boundary was connected to the large motu to the west by continuous forest. Site 5 was centred on an abandoned settlement and was used as our campsite in the large motu to the south. Site 6 was located in the northern third of the large western motu. Ideally all sites would have been sufficiently isolated from neighbouring parts of the island to prevent rodent movement in or out, but this was not possible.

A uniform 25 × 25 m grid was cut and marked across each site. We used non-toxic Pestoff® 20R 2 g baits containing the biomarker pyranine at 0.2% for the bait trial. Three different bait application rates (5, 10 and 15 kg/ha) were randomly allocated to Sites 1–5 (Fig 1). Insufficient bait was available to treat Site 6 and crab density only was measured at this site. Bait was spread in two separate applications at the specified rates one week apart. To simulate an operation relying on hand broadcast or aerially spread baits, bait spreading was completed by hand. An amount of bait matching the prescribed application rate was spread from each 25 m grid point using a cup that contained a fifth of the required measure. Bait was thrown in an arc once to the north, once to the south, east and west out to a distance of 12.5 m to ensure an even spread. The fifth and final measure was scattered within a few metres of the grid point.

Forty four 10 × 10 m quadrats randomly located across the five sites where bait was laid were established to assess bait take. Following bait application, the number of baits within each quadrat was counted to assess the uniformity of bait spread. Baits were then added or removed from each quadrat until the number of baits reflected the average application rate for the site. This equated to 28 baits per quadrat at the 5 kg/ha application rate, 56 for 10 kg/ha and 84 for 15 kg/ha. Bait take was monitored each day thereafter for six days by counting the number of baits within each quadrat at all sites. For each quadrat, the rate of bait take was calculated as the number of baits taken divided by the number of days monitored provided that there was bait left at the end of this period. If all of the baits were consumed before the end of the six day period, then the rate of bait take was calculated as the number of baits taken divided by the number of days until no bait remained minus one half. These rates were used as the response variable in an ANOVA to investigate how bait take varied over time, between sites and between quadrats (within sites). A square root transformation of the bait take rate was used to stabilize variance.

Two hermit crab species *Coenobita brevimanus* and *C. perlatus* were present on Vahanga along

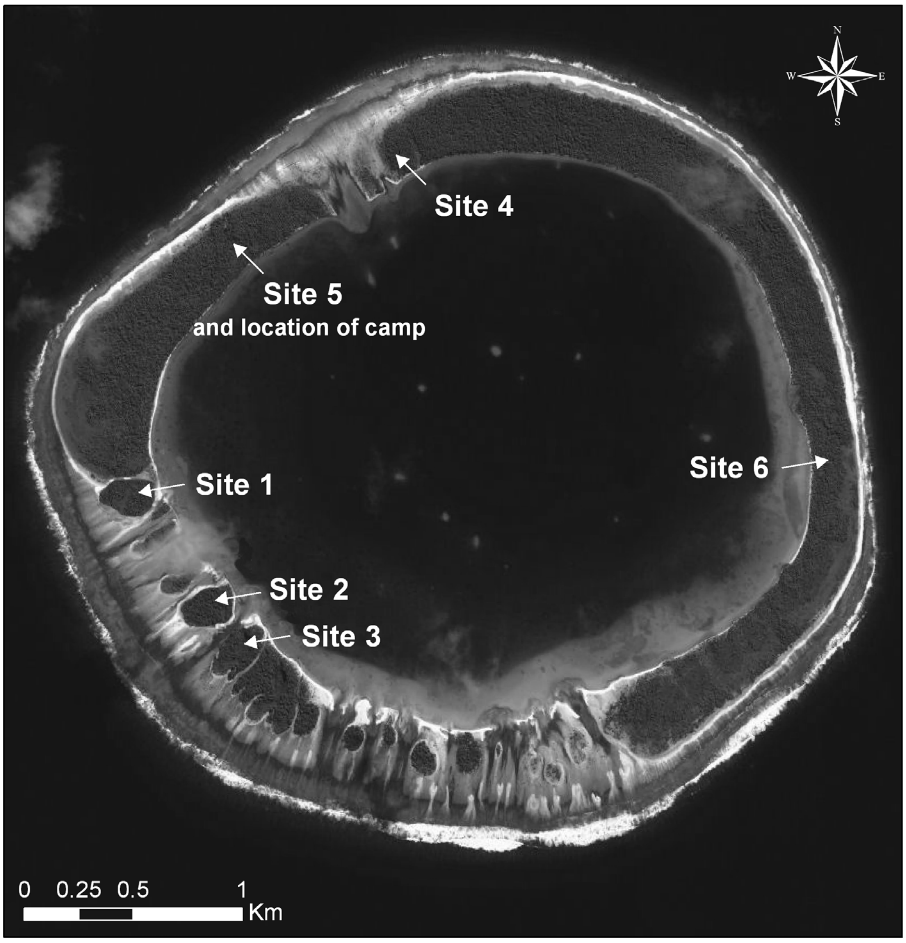

Fig. 1. Vahanga Atoll, Tuamotu Archipelago, French Polynesia showing location of study sites and rates of bait application.

with two land crab species, the predatory *Geograpsus crinipes* and the coconut crab *Birgus latro*. Only one species *C. perlatus* was judged to be sufficiently abundant to affect bait take. All other species were either localized in distribution (*G. crinipes*) or uncommon (*C. brevimanus* and *B. latro*). Only two individual coconut crabs were seen during our visit. For these reasons when estimating crab density we focused solely on *C. perlatus*. We also only counted individuals greater than 10 mm in size because small individuals were rarely seen and considered unlikely to have had an impact on bait take.

We used two methods to estimate the density of *C. perlatus*. The first, the "walking transect method", counted individual crabs at night in the light of a head torch within 2 m of both sides of a transect, while walking at a steady pace of approximately 4 km/hr. Fifty four transects of varying distance (total distance 14.2 km) were established across the six study sites to test this technique. The second, the "quadrat method", relied on counting crabs in the 44 quadrats described above. All transects and quadrats were sampled on three separate occasions to assess changes in density over time. Although crabs were active during the day especially in overcast conditions or during rain, crabs were only counted at night (during the first two hours after sunset) after early attempts during daylight hours proved that crab distribution and abundance during the day was highly clumped. Habitat variables including vegetation cover, distance to vegetation edge and distance to water were measured for each quadrat to assess any habitat preferences that may have existed for foraging crabs. Rats were also counted while completing walking transects to provide a measure of rodent density between sites.

Density estimates for both crabs and rats and their standard errors were calculated using the standard statistical formulae (Seber 1982). The quadrat method assumes that quadrats represent a simple random sample from the grid of quadrats available for each site and the transect methodology assumes that the surveyed transects are randomly selected. Quadrat data for crabs were used to compare crab densities over time, between sites and between quadrats (within sites) using ANOVA. For this purpose, only data for sites 1, 2, 3 and 4 were used since counts made at these sites were completed at the same time providing a balanced set of observations. The square root of crab counts was used as the response variable. Generalized linear models were also used to investigate the relationship between crab density and three plausible explanatory variables: distance to water's edge, distance to vegetation's edge and presence/absence of vegetation. In this case the average number of crabs (averaged over time) for quadrats was used as the response variable.

Snap trapping with Victor® Professional rat traps was completed post bait application to determine bait consumption, but was not used to evaluate rat density as the probability of trapping rats could not be determined within the timeframe of the trial. Traps were set at points on the grid approximately 30 cm above ground level either by nailing them to the base of a tree or by tying them to a coconut leaf bent down to the ground. Traps were baited with a piece of fresh coconut that was replaced on a daily basis. Trapping commenced on the fourth night after each application of bait and ran for four nights. Rats trapped post bait application were dissected and if necessary examined under UV light to determine if they had consumed bait. To reduce the risk of capturing rats moving from unbaited areas, traps were positioned at grid points a minimum of 50 m from the extremities of the baited area.

RESULTS

Excluding the time spent travelling between and within sites, we spent 23 person hours counting crabs on transects and 20 person hours counting crabs in quadrats. Crab density estimates suggest that the quadrat method was generally more sensitive at detecting crabs than the transect method but also that there is a strong correlation between the two methods (Fig. 2). If pairs of estimates for the two methods that were made either on the same day or within one day of each other are considered then they have a correlation of 0.81. They also provide clear evidence that crab density varied between (site 5 had a particularly high density of crabs) and within sites (Table 1). For any given site, density estimates were consistent when taken within a day or two of each other, but could differ substantially if the dates differed by a week or more.

During the day crabs tended to be secreted in the shade predominantly on the forest edge, under vegetation or at the base of trees. However, although our quadrat estimates of crab densities (based on night surveys) indicated a patchy distribution of crabs we could not find a GLM model that established a relationship between crab density and the presence of vegetation, proximity to vegetation edge or distance from water. It appears that if such a relationship exists during the day, it breaks down when crabs are foraging at night.

Intensive and extensive trapping (totalling 1800 trap nights) across Sites 1-5 revealed only one rodent species *Rattus exulans*. *R exulans* was distributed throughout the atoll although density as determined by walking transects varied significantly between some sites (Table 2) and appeared to vary between days. Estimates of rat density ranged from 0.9 to 27 rats per ha. Trapping could have provided a better index but the probability of capture would have had to be determined and on this expedition, time was limited. Raising traps 30cm off the ground proved an effective means of trapping rats whilst at the same time reducing crab interference.

Monitoring of bait spread showed that a sufficiently even distribution of bait was accomplished with a standard deviation less than that of the mean for all application rates. Analysis of bait take data found no evidence of any difference over time or between sites but there was strong evidence of a difference between quadrats (within sites) (Table 3). Figure 3 shows a plot of the observed rates of bait take for quadrats in sites 1 through 5. Following bait application, bait disappeared overnight from quadrats within Sites 2 and 4 where bait was spread at the lowest application rate of 5 kg/ha. After two nights bait had also disappeared from quadrats where bait was spread at 10 kg/ha (Site 5) and three nights after the second application bait had disappeared from a proportion of quadrats at all five sites.

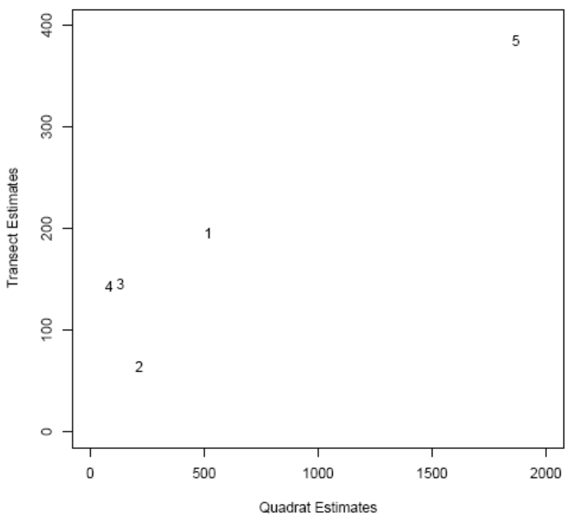

Fig. 2. Comparison of two methods used to estimate the density of C. perlatus at five sites on Vahanga.

Table 1. ANOVA of crab density as determined by the quadrat method.

Source	df	SS	MS	F	p-value
Dates	2	1.478	0.739	0.949	0.439
Sites	3	40.550	13.517	4.156	0.014
Quadrats (within sites)	36	106.991	2.972	5.956	<0.001
Dates × Sites	6	4.676	0.779	1.561	0.171
Dates × Quadrats	72	35.900	0.499		

Table 2. Estimates of crab and rat density and bait take (averaged over time).

Site	Crab density (per ha) quadrat average	Rat density (per ha) transect average	transect average	Average rate ofbait take
1	517	195	8.2	10.6
2	215	63	0.9	7.2
3	133	146	10.7	8.0
4	83	143	3.0	7.4
5	1869	385	27.0	22.8

N.B. Estimates of rat density are not considered reliable because of the high levels of disturbance from the walking transect method used. We consider this technique to have greatly underestimated rat density.

Table 3. ANOVA of rates of bait take.

Source	Df	SS	MS	F	p-value
Dates	1	5.567	5.567	2.752	0.196
Sites	3	8.604	2.868	0.728	0.561
Quadrats (within sites)	36	122.98	3.416	2.277	0.008
Dates × Sites	3	6.070	2.023	1.349	0.274
Dates × Quadrats	36	54.015	1.500		

Sites 2 and 4 were similar as they each had one quadrat with a very high rate of bait take (>50 baits per day) in comparison to the other nine quadrats (<10 baits per day). Sites 1 and 3 were also similar as they each had observed rates that ranged from near 0 up to approximately 20 baits per day. The rates for Site 5 ranged from 17 to 30 baits per day and thus this site had the highest rates of bait take. If the two unusually large values for sites 2 and 4 are deleted and the ANOVA rerun as before, then evidence of a difference between days ($p = 0.03$) and weak evidence of a difference between sites ($p = 0.11$) is found in addition to the evidence of differences between quadrats ($p = 0.01$).

Table 2 summarizes the site estimates of crab density, rat density and rates of bait take. Both sets of estimates of crab density are strongly correlated with rates of bait take. For quadrat estimates the correlation is 0.996 whereas for the transect estimates it is 0.965. There is also a strong correlation between the two sets of crab density estimates (0.941) and between the rat density estimates and the rate of bait take (0.949). These relationships are shown in Figures 4 and 5. Despite bait take by crabs, all 151 rats caught across Sites 1–5 had consumed bait, as evidenced by green staining of the gut and gut wall from the pyranine dye.

DISCUSSION

The close correlation between the two methods we used to assess crab density, and the agreement of the data with our anecdotal observations, suggest the two methods may be a useful tool for indexing crab numbers. We consider the higher estimates of crab density provided by the quadrat method to reflect actual crab density better because the method likely provides a higher probability of detection. It is easier to find crabs by torchlight when searching a small area intensively than searching for crabs while walking at a steady pace. However, the transect method covered a greater area in a shorter period of time and may be useful in situations where time is limited. We recommend the methods are compared against each other elsewhere and if possible compared against a total population count to validate their efficacy.

The greater spatial variation in crab density we encountered during the day suggests that sampling should be undertaken at night. However, if conducting field work at night is impractical, we recommend increasing the intensity of sampling effort beyond that of our trial. We consider our methods applicable to hermit crab species such as *Coenobita perlatus* and *C. brevimanus* because they are slow moving and relatively unaffected by disturbance, but they are unlikely to be suitable for the more mobile and easily disturbed land crab species such as Gecarcoidea spp. (Bright and Hogue 1972; Bliss *et al.* 1978).

One of the prerequisites for eradication success is exposure of every individual within a target population (Bomford and O'Brien 1995). In a rodent eradication, bait must be available everywhere for long enough to ensure that every individual encounters bait and consumes sufficient bait to ingest a lethal dose (Broome *et al.* 2010 in litt.). An understanding of the factors affecting bait availability especially in an unknown environment must be gained to ensure these criteria can be met. On mesic-tropical islands, where land crabs are abundant, ascertaining potential rates of bait take should be an essential component of this assessment. Any gaps created following bait application could result in a failed eradication attempt (Towns and Broome 2003).

Crabs were in sufficient numbers (up to 5 900/ha) on Vahanga to reduce bait availability over time rapidly and at some sites and at some application rates, reduced the amount of bait available to zero in less than one night. The spatial variability we found in crab density especially within sites on Vahanga was not unexpected and corresponds with observations elsewhere (Burggren and McMahon 1988). However, the result adds to the challenge of planning a rodent eradication because impacts on bait availability, as observed on Vahanga, are never likely to be uniformly spread across an island. On Vahanga, Site 5 supported the highest crab densities and was also the site where we recorded the highest rates of bait take, but we were only able to discern this by exploring the island and sampling at a range of sites.

The comparatively low numbers of rats and the absence of any other major consumer suggest that crabs were responsible for the majority of bait take on Vahanga. Crab density estimates and levels of bait uptake were also closely correlated. In such situations, a survey of crab populations may be sufficient to predict levels of bait take and guide decision making on bait application rates for a rodent eradication. However, we recommend this hypothesis be tested more widely before being applied. For islands with a different suite of crab species and/or other non-target species present, we recommend conducting bait uptake trials to assess how long bait remains available to rodents.

Our trial demonstrated that even at the lowest bait application rate or in the presence of the highest numbers of crabs, rats were able to access bait. The result suggests that achieving rat eradication on mesic-tropical islands, with comparable levels of non-target bait consumption, could be possible at bait application rates similar to those used in temperate climates. However, our trial did not quantify whether rats consumed sufficient bait to ingest a lethal dose of toxin. For this reason we recommend a precautionary approach be applied when considering bait application rates. We recommend two applications of 15 kg/ha for a future rat eradication attempt on Vahanga because at 15 kg/ha on Vahanga, bait was available to rats for at least three nights after each application (six nights in total) providing greater surety that all individuals will be exposed. Aside from crabs we encountered no logistical issues that could jeopardize the success of a future rodent eradication operation on Vahanga.

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